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Essential Tools for Water Resources Analysis, Planning, and Management

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Essential Tools for Water Resources Analysis, Planning, and Management

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ISSN 2364-6934 ISSN 2364-8198 (electronic)
Springer Water
ISBN 978-981-33-4294-1 ISBN 978-981-33-4295-8 (eBook)
https://doi.org/10.1007/978-981-33-4295-8

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

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Correction to: Essential Tools for Water Resources Analysis, Planning, and Management C1
Omid Bozorg-Haddad

Chapter 1
Modeling and Simulation in Water Resources Management

Masoumeh Zeinalie, Omid Bozorg-Haddad, and Barkha Chaplot

Abstract One of the most crucial and influential factors in the formation and development of a civilization is the available water resources. The most common and practical way to manage water resources is to model and simulate water systems. In general, modeling is the mapping of a natural phenomenon in the form of physical components or mathematical relationships and involves both physical modeling and mathematical modeling, which are used in mathematical modeling in water resources management issues. Simulation is one of the methods for solving mathematical programming models in situations where the use of algebraic analysis methods is not possible or cannot be tested in the real world. Simulation-based on trial and error examines the effect of different conditions on the system and evaluates the results. With the above-mentioned explanations, through modeling and simulation, in the least time and cost, researcher investigate different options for achieving the goal. This chapter includes details of modeling and simulation in water resources management.

Keywords Mathematical modeling · Simulation · Water resources · Trial and error · Experiment · Natural phenomenon

The original version of this chapter was revised: For detailed information, please see Correction. The correction to this chapter is available at https://doi.org/10.1007/978-981-33-4295-8_14

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O. Bozorg-Haddad (ed.), *Essential Tools for Water Resources Analysis, Planning, and Management*, Springer Water, https://doi.org/10.1007/978-981-33-4295-8_1

1.1 Introduction

Nowadays, modeling, simulation and optimization are widely used in water resources management. To this end, numerous articles have been published on water resource modeling and simulation. Belaineh et al. (1999) have investigated the simulation and optimization of a hypothetical zone model with more focus on water use management and reservoir management under different scenarios. Their results indicated that the more details used in the model, the better the shared water management would be so that the model with the most detail was 13% more water. Khoshfatrat et al. (2006) model the optimal use of multi-barrier systems, simulation method with the limited operation and trial and error to determine the optimal water transfer pattern from the upstream dam to the downstream dam in a three-dimensional system (including two consecutive two-way systems) used monthly intervals. In this study, a simulation model of water resources analysis has been used and its unique features for modeling optimal water transfer in two-dimensional systems have been shown. The dams studied include Zayandehrood, Koohrang (1) and Sardar dams, which both located in Iran. Khayami et al. (2007) in their study, using Simulation Reservoir Dynamic Model and available statistics, evaluated water quality conditions of the Torogh dam reservoir located in Iran, in terms of temporal changes in temperature, salinity and dissolved oxygen parameters. The results showed that in high water years such as 1998, when the inflow discharge exceeds its long-term average discharge, due to the high water level (more than 50 m), the thermal stratification is complete from mid-spring. It occurs within the reservoir until late summer, which results in changes in the chemical, biological and physical properties of the water at different levels, but in years such as 2002 due to the low volume of inlet water and the relatively high average annual temperature, the water level in the reservoir decreases by about 16–20 m. In these conditions, the thermal layering either does not form or, if formed, starts earlier in time and shortens the installation period. Hooshmandzadeh (2007), after presenting the principles and foundations of simulation of water resources systems, has briefly reviewed the simulation of the water resources system of the Sante reservoir dam in Kurdistan province of Iran. Hitchcock and Collins (2007) reviewed several criteria for water resource management and planning analysis. Samadyar and Samadyar (2008) examined the process of modeling and simulation in water resources and what models are eligible for simulation. They have defined the steps of modeling and simulation in such a way that first the preparation of the model is appropriate to the goal, then the initial simulation and completion of information, model calibration, model approval, uncertainty analysis, sensitivity analysis and finally providing management solutions. Azari et al. (2009) simulated and warned of floods by combining hydrological models in GIS and estimating rainfall by remote sensing in Golestan province in Iran, especially the Mother river basin, due to its flooding. Since the precipitation on August 11, 2005 has led to floods in this area, images of NOAA satellite measuring AVHRR have been selected for this study. In this study, first, all the required layers in GIS were prepared and made based on the factors influencing the flood, then the local database of the required parameters including river route, cross-sections, coasts, for runoff flow and MODClark network precipitation model was formed and it has entered the hydrological model. NOAA/AVHRR satellite data, object-oriented classification and cloud index method has been used to detect and classify clouds and estimate rainfall, respectively. Thus, the amount of precipitation was estimated by each of the classified clouds. Also, through soil maps, land use and other inputs of the hydrological model, the amount of runoff due to rainfall is estimated and finally, due to the topographic situation of the region, the depth and speed of water flow from this runoff from the hydraulic model GIS and re-sent to the environment and the flood map was obtained. In this study, by combining remote sensing data in the form of satellite images and precipitation-runoff model and hydraulic model, the extent of flood spread in the region was determined. The results of this study revealed that with the help of object-oriented cloud classification, acceptable results can be achieved, and the overall accuracy of the classification is estimated to be about 0.905 and the cap coefficient is estimated to be about 0.887. According to the flood hydrograph obtained between the upstream and downstream of the basin, and assuming the onset of calculations from the onset of precipitation in the study area, the flood zone, and its occurrence was predicted to be between 20 and 33 h earlier than the flood peak. Meyer and Monzehrnands (2009) reviewed the optimization of accumulated models of water resources. Abdo Kolahchi et al. (2010) simulated the performance of the underground dam using metal sheets with a thickness of 0.5 m in the Hosseinabad Strait area of Isfahan in Iran and used PLAXIS software for modeling. Salavi Tabar et al. (2011) simulated the combined surface and groundwater resources of the Haraz River catchment area. For this purpose, after evaluating and estimating the surface water resources in the basin and accurately determining the amounts of surface and underground uses in different parts of the Haraz River catchment area in Iran, to model the surface and underground water resources separately by mountain and plain with interest. The system dynamics method is taken with Vensim software. Finally, the performance of the Haraz river catchment area has been combined and analyzed according to the water cycle in surface and groundwater resources and return water from consumption, losses in the basin level and the amount of aquifer storage has been calculated as the output of the model. Finally, it can be said that the results of this model can provide a solution for evaluating and examining the components in the water cycle to conduct more strategic management to use water resources in the basin. Komasi et al. (2015) have modeled the phenomenon of dam failure. In this regard, the output hydrograph was calculated from the dam failure and then, due to the downstream morphology, flooding was carried out. This study evaluates the comparison of the results of Mike11 software with the results of the analytical solution for flood hydrograph due to the failure of Dez Dam in Iran and the results of experimental equations. The results of this study indicate that the effect of flood peak due to the failure of Dez Dam is only 30 km below it and in the area of Dezolia Dam in Dezful city in Iran and is not essential for other areas of the river. The results also showed that the Dez Dam, if broken, floods about 60,000 cubic meters per second to the city of Dezful and 11,000 cubic meters to the city of Ahvaz. Moradi et al. (2015) simulated the resources and expenditures of the Tajan Irrigation and Drainage Network of Mazandaran Province, Iran. They used the dynamic model of the Vensim system and software for this operation. According to their results, on average, over 214 million cubic meters per year at the diversion dam or 286 million cubic meters per year on the coastline, the excess water of the Tajan River basin system, located in North of Iran, can be transferred to the adjacent river basin.

Zeinali et al. (2020a, b), in a study of the interaction of surface and groundwater through their systematic simulation and creating a dynamic atmospheric connection between surface water and groundwater resources in the Loor-Andimeshk plain, located in southwestern Iran, by relevant mathematical models. They have reviewed it. Based on this, the hydrological soil moisture method and MODFLOW model were used to simulate unsaturated and unsaturated areas, respectively and the study revealed the interaction between surface and groundwater in any spatial and temporal period, in the form of a coupled model. Radmanesh et al. (2020) used the Madflu conceptual model and intelligent simulator models to model the hydrograph representing the aquifer. Finally, the results showed that the MODFLOW and GEP models, among the similar intelligent simulator models, performed almost the same in aquifer hydrographic modeling.

Zeinali et al. (2020a, b) examined the link between genetic algorithm II and a coupled surface and groundwater model in southwestern Iran. The advantage of this structure is the achievement and maintenance of the equilibrium balance between surface and groundwater, taking into account various limitations. Therefore, the structure of the proposed model can provide decision-makers to simulate the interaction of outputs between surface and groundwater and to calculate the simultaneous decrease in river flow and groundwater, especially in dry years.

1.2 Definitions and Terms

In the last decades, the use of various models, especially mathematical models, has become widespread in various sciences. The model is an abstract representation of the components and relationships of a phenomenon that exhibits the relationships between the various entities and/variables of that phenomenon. Since it is not possible to experience all the facts and phenomena practically, models are used to depict events, facts, or situations. Managers, for example, can measure the impact of different advertising tools (newspapers, television, and billboards) on sales using statistical models.

In general, modeling is the art of judging how to summarize the components of the real world that are important in decision-making and can be described in a few ways. Therefore, modeling requires judging the expression of these components and the relationships between them in the mathematical language (Bozorg-Haddad and Seifollahi Aghmioni 2013). Scientific modeling is a scientific activity to make it easier for a part of the phenomenon or the world in general to understand, define, see, determine quality or simulate by referring them to available and accepted knowledge. This requires identifying and selecting different aspects of the phenomenon in the real world to build different models for different purposes, such as conceptual models to understand, practical models to perform operations, mathematical models to determine quality and graphical models for illustrating the subject (Cartwright 1983; Hacking 1983).

Simulation is the implementation of a model in which the fundamental features of the system appear. Using simulation, it is possible to study the impact of different conditions on the system and analyze the results. The basis of the study of different conditions in system simulation is based on trial and error (Bozorg-Haddad and Seifollahi Agmuni 2013). Simulation is a kind of revitalization of the model and shows how an instance or phenomenon behaves. Simulation is used to test, analyze, and train real-world systems that can be modeled. For example, in a water resource system (a system is a set of related components that converts multiple inputs into multiple outputs), if the system outputs are unknown for its inputs, the system is called simulation. The outputs of the system can be determined and can be determined according to different input conditions (Bozorg-Haddad and Seifollahi Agmuni 2013).

There are two types of simulation: static and dynamic. Static simulation provides system information at a specific and constant time, and dynamic simulation provides system information over time.

Water resources management involves identifying and developing water resource projects to maximize net profit or minimize costs, including useful non-commercial items such as potential ecosystems for destruction and negative social impacts (Mir and Mons Hernandez 2009). In this regard, water resource models are used to make decisions about water supply, ecological restoration, and water management in complex systems (Loux 2008). Simulation and optimization are the two main approaches to the river basin model. In water resource simulation, its behavior is simulated based on the set of rules governing water allocation and infrastructure operations (McKinney et al. 1999).

1.3 Fundamentals and Logic of Modeling and Simulation

Models are often used when it is impossible to construct laboratory conditions and samples that directly measure results. Direct measurement of results under controlled conditions has always been more accurate and reliable than models constructed from results (Tolk 2015).

One of the essential aspects of modeling is cognition. That is, in similar modeling models mentioned above, the purpose of modeling is only to understand the model environment. Another aspect of modeling is an explanation. That is, sometimes, a model is presented to introduce and present the properties of a real entity. Geography is an excellent example of this aspect of modeling.

So it can be said that the purpose of modeling is two things:

(A) Cognition (B) explanation

In general, models can be segmented from comprehensibility, nature and structure.

Table 1.1 The three divided classes of the models

Equations are known Physical knowledge Information under model	Primitive sciences Model information	Model information Displaying inputs and outputs
White	Gray	Black

From an understandable perspective, the model is divided into three classes: gray box, white box and a black box. In white-box models, the process that goes into the model is clear. In the gray box models, what happens in the model is not clear. These models have an interface between white box and black box models. In black-box models, what happens in the model is unclear (Table 1.1).

In terms of nature, models are divided into four categories: physical, deductive, mathematical, and computer and laboratory models. In the physical model, the model is physically similar to the actual model, but on a different scale. For example, the physical model of a dam or river provided by hydraulic laboratories are examples of physical models. Physical models have a special place in the world right now. These types of models are usually expensive. In scaling models, the rational basis is that there are various phenomena in nature that are similar in physics and mathematical equations. For example, the movement of electric current or heat movement is in many cases similar to the physics of water movement.

Accordingly, it can be assumed that the pressure equivalent voltage, the electrical conductivity equivalent to the permeability coefficient, the electric potential gradient equivalent to the hydraulic gradient, and the electric current intensity vector are equivalent to the water velocity vector. In this case, the formula of ohm is used instead of the Darcy formula. Mathematical models are meant to solve the basic equations of the subject, which in water engineering are the equations governing soil and water physics. The steps that go into creating and implementing a mathematical model generally include:

(A) Understanding the physical behavior of the system: At this stage the relationships and interactions of the factors within a system are determined.
(B) Mathematical Equations Definition: At this stage, the physical relationships that have been identified in the previous step are interpreted as mathematical expressions. In this section one should consider simple assumptions and obtain the equations governing the flow. The results of this step generally include one or more differential equations with appropriate initial and boundary conditions.
(C) Solving Mathematical Equations: At this stage, a proper solution to the formula presented in the previous step must be obtained.

There are generally two basic methods for solving mathematical equations at this stage, which are the analytical method and the numerical method. On this basis, two types of mathematical models can be defined: analytical mathematical models and numerical mathematical models.

Many computer programs are commonly used to analyze mathematical models today. Computer models are mathematical models, but they are called computer models because they are analyzed by computers. The use of these types of models is nowadays widespread. This is because of the simplicity and low cost of these models.

In modeling and simulation, the task-oriented, concise, and purposeful model is an abstraction of a real phenomenon and consisting of physical, legal, and identified constraints (Tolk 2015). The model is task-oriented because it comes with a question in mind or a task. It is brief because it eliminates all observed and identified entities and their interactions with each other if they are not relevant to the purpose. It is digest because it collects all the information it needs. Both the brief and the abstract are purposefully done. However, they are all built on a real phenomenon. The phenomenon, if accompanied by physical limitations, is itself a model in itself. In the meantime, there are limits to what we can see using existing methods and tools. There are also cognitive limitations that limit us to what we can explain using existing theories. Such a model incorporates concepts, behaviors and relationships in a formal format and is known as a conceptual model. To run it, the model must be run by simulation software. This requires more than quantitative estimates or the use of discoveries (Oberkampf et al. 2002). Despite all the cognitive and computational constraints, simulation is considered to be the third pillar of scientific methods, because there are three options for examining a real system: conducting experiments, forming theories, and simulating, which is shown in Fig. 1.1.

In the process of modeling water resources, firstly, one must understand the nature of the problem. To this end, the purpose of modeling should be clearly defined for the modeler. Also, prediction of system behavior based on simulation methods, if not using physical mechanisms, can lead to incorrect results. Even when the model can fully represent the original design, incomplete results are obtained if sufficient

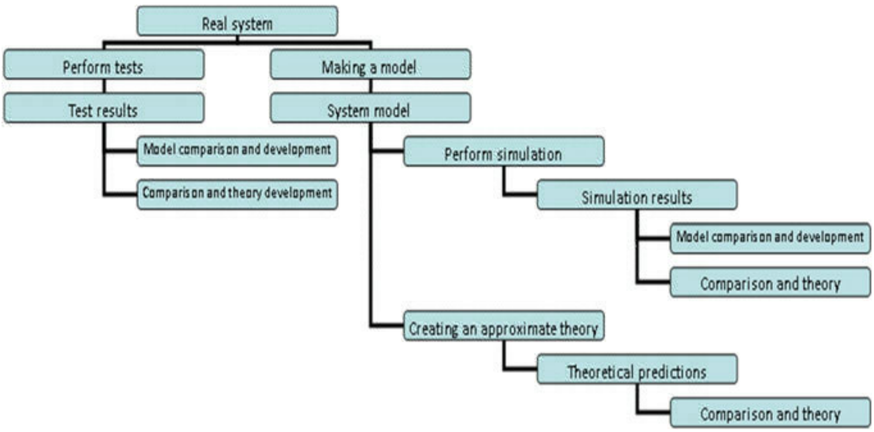

Fig. 1.1 Flowchart showing the relationship among experiment, simulation and theory

data and information are not available for estimation and rate constants (Torabian and Ashami 2002).

In the area of water resources, the issue of groundwater is one of the important topics. In general, any system that can show the response of groundwater storage to the stresses inflicted is called the groundwater model. Overall, groundwater modeling is the simulation of water movement in porous environment. An underground water the model has been simplified form of an underground water system that shows the correlation between hydrodynamic reaction and reaction. Groundwater models are also generally divided into three categories: physical, analog, and mathematical.

1.3.1 Physical Models

These models have attempted to create simplified conditions of nature in the laboratory. The aquifer elements are used to construct these models, namely, the water and the type of soil-forming the aquifer. These models are made on a smaller scale, depending on the type of aquifer, their principles, and their natural physical properties. Examples of such models are models created in the laboratory for checking dam construction, channel overflow, etc. Aquifer modeling is difficult and costly in most cases due to natural conditions and often unknown to them.

1.3.2 Analog Models

Such models are built on the similarity of mathematical equations that express physical phenomena in aquifers and other systems.

1.3.3 Mathematical Models

Mathematical models are either deterministic or probabilistic or a combination of both. The probabilistic model provides the whole range of solutions based on the probability of incidence and is often used to predict flood and rainfall. Certain models are based on the cause and effect relationships of recognized systems and processes and are generally used to solve regional groundwater problems. These models are also classified into numerical and analytical models.

1.3.4 Analytical Models

The purpose of analytical models is to obtain a precise mathematical solution from the description of physical processes. However, the groundwater flow equation is subject to analytical methods and requires simplification of system assumptions involving both initial conditions and boundary conditions. These models are used for pumping tests to estimate aquifer parameters, excavation calculations, inverse solutions to interpret water flow experiments and to evaluate numerical models.

1.3.5 Numerical Models

In numerical methods, the aquifer is subdivided into small elements and an equation is obtained for each element whose overall form is approximately the same for all internal elements. This equation can be approximated by one of the numerical methods. The result of this approximation for each equation is the production of an algebraic equation that yields a total $n \times n$ matrix for the aquifer in question. (n is the number of elements).

1.3.6 Definitive Simulation Models

Definitive simulation models of water resources systems do not consider uncertainties in hydrological parameters and variables. As a result, these models present limited planning and management issues. These models are generally used for initial decision making and general comparison between different options, and for more accurate decisions, uncertain models should be used. For the preliminary analysis of designs, before studying more closely the random simulation optimization, definitive models can be useful using selected values of inputs, parameters, and variables. The basis of most models for simulating water resources systems is the law of mass conservation, often called quantitative or qualitative balances. For example, in simulating the volume of water reservoirs in a dam reservoir, based on the law of mass conservation or continuity equation, the volume of the reservoir at the beginning of period t, the inflow rate, the volume of the reservoir at the end of the previous period, the amount of outflow during a similar period. It depends on the buildup, evaporation, infiltration and other available water. Other models of quantitative simulation of water resources systems include the runoff rainfall model which is widely used in studies of flood management and control. Various deterministic simulation models have also been developed to study the temporal and spatial variations of water quality in river systems and reservoirs. Following is one of the definitive simulation methods.

1.3.6.1 Artificial Neural Networks

The Basics of Neural Networks

Artificial neural networks are based on the biological model of the animal brain. These networks are essentially a data-processing system that is derived from the generalization of their mathematical models. Artificial neural networks are systems that are capable of performing functions similar to the human brain. Neurons are divided into three categories of sensory neurons, stimulus neurons, and communication neurons based on the structures between which messages are directed. Artificial neural networks (ANNs) or, more simply, neural networks are new computational systems and machine learning techniques, knowledge representation and, ultimately, applied knowledge to predict the output responses of intricate systems. The idea behind such networks is partly inspired by the way the biological nervous system works for processing data and information, for learning and knowledge creation. The main element of this idea is the creation of new structures for the information processing system. The system consists many of highly interconnected processing elements called neurons that work together to solve a problem. Using computer programming knowledge, one can design a data the structure that works as a neuron, then create a network of these interconnected synthetic neurons, create a learning algorithm for the network, and apply it to the network.

Mathematical Modeling Basics of Artificial Neural Networks

(A) Artificial Neuron Model

A neuron is the smallest information processing unit that forms the basis of the performance of artificial neural networks. Synthetic neurons were designed to mimic the basic characteristics of biological neurons.

(B) Single-layer artificial neural networks

Although a single neuron only shows stimulus functions with a certain simple scheme, the main power of neural computation is due to the connections of neurons in the network. The simplest network is a group of regulated neurons, in one layer.

(C) Perceptron Multilayer Network

The artificial neural network consists of several computational units called neurons. The artificial neural network is a kind of parallel processor system and has the following characteristics: 1. Neural neurons are network processors. 2. Network connections have a particular weight that affects traffic signals. 2. Each neuron calculates its weighted sum of inputs and outputs it after passing the threshold function. The weights of network connections change during the training procedure according to the learning law, and after the realization of learning and the fixed weights act as network memory.

(D) Comparison of monolayer and multilayer neural networks

Multilayer neural networks have more capability than monolayer networks. Two-layer feedforward neural networks are able to approximate any function accurately, while single-layer artificial neural networks do not.

(E) Notes

Artificial neural networks are composed of several processors called neurons with cells and units operating in parallel. Neurons, in themselves, are test functions, but as a whole in the form of a network, they can solve complex issues ranging from estimating work progress rates to estimating the pre-stress of lift cables.

(F) Education

Learning capability means the ability to adjust network parameters with the passage of time as the network environment changes and the network experiences new situation. Most training algorithms are based on supervised training. The convergence of these algorithms is mathematically proven so that in the generalized Delta method, the first derivative of the total error is used to adjust the weights, which reduces the total error by applying this method.

(G) Generalization

The purpose of training is to make acceptable estimates within the optimal range of the problem. Factors affecting neural network generalization capability are a type of network and training algorithm, number and texture of middle neurons, number and distribution of training patterns. The power to extend artificial neural networks is based on interpolation. Despite this potential, extrapolation-based generalization is also important. It can be said that the network learns the function, learns the algorithm, or obtains the appropriate relation for some points in space.

(H) Several middle neurons

In general, there is no straightforward way to determine the most appropriate number for mid-layer neurons, and this is especially complicated when the number of mid-layers is increased. Unless there are very few intermediate neurons in the network, it will not be possible to obtain an accurate model of all forms of the response surface. In attempting to resolve this problem, a range of tissues of different midline neurons is usually considered and the tissue that works best is accepted.

(I) Network Evaluation

The value of the results needs to be determined before applying a neural network. The evaluation usually involves determining the effectiveness of the network on test issues that are not used in network training but are suitable for comparison. The test questions should be chosen so that they do not fit into specific educational patterns.

(J) The shape of data and how it is expressed

The input and output data of a network are usually continuous or discrete. However, sometimes they may be parametric with a combination of all of these.

(K) Network Training Method

The algorithms used can be varied depending on the type of problem discussed, but the form of training can be either by simply adjusting weights or by adjusting the network structure.

Nonlinear (probabilistic) simulation models

Stochastic simulation models combine deterministic and probabilistic models and allow the probabilistic properties of some system variables to be considered. Nonlinear simulation models usually use information such as the distribution of probable variables, the number of times they are repeated, and their mean and range of variation, and generally the simulation results are presented as probabilistic. One of the conventional methods of nonlinear simulation of water resources systems is the Monte-Carlo method. In this method, according to the statistical properties of the random variables of the system, value is randomly generated for each variable and the system is generated based on these values and the values of the definitive input variables are definitively simulated. By repeating this process, the statistical properties of the output variables can be estimated. Uncertainty is always a part of the planning process because many quantities of factors affecting the performance of water resources systems cannot be fully ascertained when designing and building the system. The uncertainty stems from the possible nature of atmospheric processes such as evaporation, precipitation and temperature (Hooshmandzadeh 2007).

1.4 The Importance and Necessity of Modeling and Simulation

As mentioned, modeling and then simulating it is one of the most important scientific methods because having the basic information about a process can use simulators such as temperature, pressure and flow rate. Access. In any existing process, computer-aided simulation enables it to be able to detect its behavior by changing operating conditions and also to find optimal conditions for reducing waste while increasing productivity (Sotudeh Karabagh and Zarif 2005). On the other hand, because we do not want to try and error repeatedly, it is possible to observe simulations at a lower cost and time if a series of events occurs or if a series of variables are introduced into the system. What will happen to the system, or what will happen if we do not make any changes and follow the same procedure? Or even if the system doesn't exist in real life and just guess what might be working on it and want to know if it does.

Optimization in some problems is one of the key steps in problem-solving, and since modeling and simulation are the basic stages of optimization, they are therefore very important in problem analysis.

Simulation is nowadays widely accepted. In 2006, the National Science Foundation (NSF) highlighted the potential of using technology and simulation techniques to revolutionize engineering in a report based on engineering science simulation. One of the reasons given for increasing interest in using simulation is that using simulation is generally cheaper, safer, and more ethical than real-world testing. For example, supercomputers are sometimes used to simulate the explosion of atomic devices and their effects in better support for preparedness in the event of an atomic explosion (Versky). Similar efforts have been made to simulate storms and other natural disasters.

One of the important applications of simulation is in industrial production. The simulation technique is a valuable tool for assessing the impact of massive investments on physical equipment or facilities such as factory machinery, warehouses and distribution and distribution centers used by engineers. Simulation can be used to predict the performance of existing or planned systems to compare alternative solutions to a particular design problem (Benedettini and Tjahjono 2008).

Another important aim of simulating production systems is to determine the quality of system performance. Types that are commonly measured in determining system performance are: (Banks et al. 2005).

1. System performance under medium and maximum load
2. System Time Cycle
3. Use of resources, workers and machines
4. Bottlenecks and blockages
5. Queuing in the workplace
6. Queuing and delays caused by systems and devices involved with the material
7. Staff Needs
8. System scheduling efficiency
9. System control efficiency

In modeling and simulation discussions, a model needs to be built before anything can be simulated. In this regard, modeling has the advantages that have become important. The benefits of modeling include:

1. More appropriate decisions.
2. Increase user insights by linking different problem variables.
3. A tool for better and more effective communication.
4. Save money.
5. Ability to investigate and predict the behavior of the system in the face of a variety of variables or parameters of a real situation.
6. Ability to analyze all possible combinations of potential factors using computer modeling.

The basic benefits of simulation discussed by Schmidt and Taylor (1970) and others are as follows: (Mahlouji 2010)

1. After building each model, it can be repeatedly applied to analyze the designs or policies proposed.
2. Simulation techniques can be used to help analyze any proposed system. However, incoming data is approximate and incomplete.
3. Generally, it is much less expensive to obtain simulation data than to provide real system data.
4. Simulation is usually easier to apply than analytical methods. Therefore, the number of potential users of simulation methods is much higher than the analytical methods.
5. While simulation models usually do not have such limitations. Using analytical models, the analyst can usually calculate only a finite number of system performance metrics, while the data generated from simulation models apply to the estimation of each performance metric.
6. In some cases, simulation is the only way to find a solution.

There have been many applications of simulation in a variety of contexts. Hayley and Lieberman (1980) provide the following examples to illustrate the broad capability of the simulation method:

1. Simulate operations at major airports by airlines to test changes in their policies and practices, such as maintenance and maintenance capabilities, passenger mounting and disembarkation facilities, auxiliary aircraft, and so on.
2. Simulate the transit of traffic junction with traffic lights with a regular schedule, to determine the best time sequences.
3. Simulation of maintenance operations to determine the optimal number of repair departments.
4. Simulate the uncharged flow of particles from the radiation path to determine the radiation intensity passing through the shield.
5. Simulation of steelmaking operations to evaluate changes in operation, capacity, and facility composition.
6. Simulate the economy of the country in terms of predicting the impact of economic policy decisions.
7. Simulating large-scale military battles to evaluate defensive and offensive weapon systems.
8. Simulate large-scale inventory distribution and control systems to refine the design of such systems.
9. Simulate all operations of each business enterprise to evaluate the wide range of changes in its policies and operations as well as provide the opportunity to simulate business operations to train managers.
10. Simulation of the telecommunications system to determine the capacity of the desired components to provide satisfactory service at the most economical level possible.
11. Simulate the performance of a developed river basin to determine the best combination of dams, power plants, and irrigation operations to provide the optimal level of floodwater flow and water resources development.

12. Simulation of production line operations to determine the amount of space needed to store materials under production.

1.5 Workflow and Flowchart

The basic steps of modeling and simulation include 10 steps as follows (Fig. 1.2):

1. **Problem Editing and Goal Setting**: To find the answer to the problem, you need to know what its purpose is.
2. So the first step in a simulation test (like any other test) is to determine the purpose of the test because it is the goal that determines how the test is done, the details needed, and the final results.
3. **System Definition**: At this point it is necessary to determine what methods and techniques can be used to study the system. The definition of a system is, in fact, the determination of the components of the system, the internal and external elements and factors of the system environment, and the parameters and variables of the system. Afterward, the relationships and rules governing the characteristics of the system and its variables are identified or formulated, then the system behavior is examined and the details of the variables change in the system are revealed.

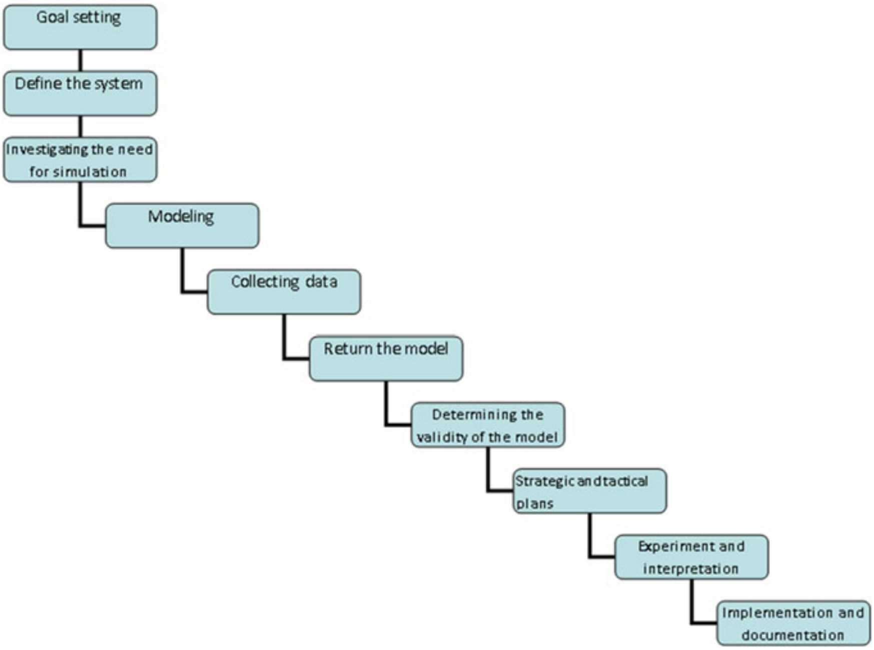

Fig. 1.2 Flowchart Modeling and Simulation Process

4. **The answer to the question**: should the simulation model be used in all decisions? If the actual conditions are not too complex and can be solved using analytical methods, naturally there is no need to use a simulation model, but if given the complex and high-risk conditions, only the simulation can be used, So the application of the simulation method will be.
5. **Modeling**: The art of modeling is the ability to analyze a problem, abstract its properties, select assumptions, and then complete and develop the model until a useful approximation of reality is obtained. The more complete the model, the more complex the situation reflects.
6. **Providing and collecting data**: Each study requires data collection. In a simulation model, the input data must be closely related to the information about the components of the system and the relationship between them. At this time, the analyst must decide what data is needed and how to collect it.
7. **Model Return**: Step 6 is removed by returning the model. At this point we need to describe a model of the computer system. Simulation models are very logically complex and have many interactions between system elements.
8. **Model validation**: This is the most important and most difficult step of the simulation process. Validation, namely, whether the constructed model accurately simulates and describes the behavior of a real system? So what matters is the reliability of the model, not the fact of its structure.
9. **Strategic and Tactical Planning**: Strategic planning means the test plan from which the desired information is obtained, and tactical planning means determining how each of the tests specified in the test plan is performed.
10. **Experimentation and Interpretation**: At this stage, planning errors and deficiencies will be identified, and the implemented steps will be reviewed.
11. **Implementation and Documentation**: The success of a simulation project can only be attributed to a researcher when the model is accepted, understood, and used. Accurate documentation of how the model is designed, developed, and operated can extend the useful life and chances of successful implementation.

1.6 Examples of Practical Simulating Methods

There are several ways to model and simulate the phenomena of water resources. Some of these important and practical methods are as follows.

1.6.1 Monte Carlo Method

The term "Monte Carlo Method" was coined in the 1940s by physicists working on a nuclear weapons project at the Los Angeles National Laboratory in the United States (beginning with the Monte Carlo method). Monte Carlo Method (Monte Carlo experience) is a computational algorithm that uses random sampling to calculate the results.

Monte Carlo methods are commonly used to simulate physical, mathematical, and economic systems. On the other hand, the Monte Carlo method is a class of computational algorithms that rely on random repeated sampling to calculate their results. Monte Carlo methods are often used when simulating a mathematical or physical system. Because they rely on duplicate calculations and random or random numbers, Monte Carlo methods are often configured to run on a computer. The tendency to use Monte Carlo methods becomes even more difficult when calculating the exact response with the help of deterministic algorithms is impossible or unjustified. Monte Carlo simulation methods are particularly useful in studying systems where there are many variables associated with the degree of pairwise freedom. These include fluids, highly coupled solids, and disordered materials and cellular structures. Monte Carlo methods are also useful for simulating phenomena with high uncertainties in their inputs, such as risk calculation in trade. These methods are also widely used in mathematics. An example of the traditional use of these methods is to estimate certain integrals, especially multidimensional integrals with complex boundary boundaries. There is not only one Monte Carlo method, but the term refers to a wide range of widely used methods. However, these approaches follow a certain pattern:

1. Define a range of possible inputs.
2. Generate random ranges from that range.
3. Using the inputs, perform a series of specified calculations.
4. Integrate the results of each computation into the final answer.

For example, we can calculate the value of p (l) by using the Monte Carlo method.

1. Draw a square on the screen, then insert a circle inside it. Next, spread several shapes of the same size uniformly (for example grains of sand or rice) across the square.
2. Then count the number of objects in the circle, multiply by four, and divide the number by the total number of objects in the square.
3. The ratio of intra-circle objects to in-square objects will be approximately equal to $\pi/4$ which is the ratio of the surface of the circle to the square. So you've got an estimate of π. Note how the estimate of λ follows a pattern specified in the Monte Carlo method.

We first defined a range of variables that was a square that surrounded our circle. We then randomly generated the inputs (distributing the grains uniformly in a square), then performed the calculations for each input (checking whether the grains were in a circle). Finally, we merged all the answers into the final answer. Also note that two other common features of Monte Carlo are:

Calculation relies on good random numbers

Gradual convergence towards better estimates when more data is simulated.

1.6.2 Las Vegas Method

The Las Vegas algorithm was introduced by Babaei in 1979 for the problem of isomorphism graph (isomorphism) as a dual Monte Carlo algorithm (Babai 1979; Grundy 2008). The Las Vegas algorithm is a random algorithm that always gives the correct answer, which means it always produces the correct answer or alerts us to the error. In other words, the Las Vegas algorithm does not gamble with the accuracy of the results, but gambles with the resources used to calculate it. A simple example is rapid random sorting in which the axis or the member influencing the sorting is randomly selected but the result is that we always have a ordered response. The Las Vegas algorithm has one limitation: it must always have finite runtime. In general, the Las Vegas algorithm can be used in situations where the number of solutions may be relatively low and where the validity of a candidate is a relatively easy solution. While the solution is complex.

Various mechanisms and conditions affecting groundwater resources cause changes in water reservoir volume and water table levels that need to be closely monitored and forecasted for proper planning, control and management. In recent years, the preparation of groundwater models and their use for simulating groundwater systems has been a major part of the projects related to the management, operation, protection and purification of groundwater. Groundwater models are often used in evaluating water resources to determine the long-term period of operation of regional or local aquifers. In particular, the flow model can provide useful information on hydraulic factors such as flow rate and flow direction. Also, subsurface conditions are not readily accessible and therefore models have become a useful tool for understanding, simulating, and predicting groundwater systems.

The following are some of the most important numerical solution methods used in groundwater:

- Border elements
- Dynamic planning
- Finite Elements
- Finite integral differentials
- Classic Limited Differences
- Random Walk Method

Among the methods mentioned above, the finite difference method is most commonly used to solve groundwater problems and is the most important numerical method for solving differential equations.

1.6.3 Finite Difference Method

The major difference between these methods and the finite elements is how the region is disrupted. In the finite difference method, the location of the points should be specified. However, various elements need to be determined in the finite element but the order in which the elements are formed does not matter. In the finite difference method, the study area is subdivided into square or rectangular elements, in which the nodes may be located within the elements or at the intersection of the grid markers. The segmentation and size of the network in the study area are determined based on the need and the degree of precision required and the shape of the area and other hydrological components that govern the area. If the study area is a homogeneous, rounded environment with a rectangular square shape and the stresses are not concentrated in specific environments, the element size is assumed to be constant, and small element size is assumed to be required in areas with high accuracy. The size of the network affects the accuracy of the results and the amount of computation.

When modeling groundwater, there is usually a simplified picture of the real world that is called the conceptual model. This model reflects the characteristics of the hydrogeological system. The most important goals of conceptual modeling are as follows:

Obtain accurate knowledge of the hydrogeological status of the area.

- Explain the problem of groundwater for a numerical model.
- Help in choosing a suitable numerical model.
- Logical simplification of the problem by appropriate assumptions.

Given that in simulation and complete reconstruction, there is usually never complete data to accurately describe a system, simplifying assumptions must be made in the conceptual model. The conceptual model should be designed to simulate the behavior of the system while being simple. One of the factors that makes the model predictions not accurate is the errors and deficiencies in the conceptual model.

1.7 Modeling Networking

To solve the partial differential equation, Environment divided into smaller components called cells. In the finite difference method, the study area is usually divided into several rectangular or square cells using two groups of perpendicular parallel lines, which, of course, the smaller the cell size, the larger the cell number, and the greater the accuracy of the calculations. In contrast, the run time of the model increases. Usually, in groundwater modeling in Iran, according to available information and statistics, cell dimensions range from 2 m to 5 km, which is either uniform or variable.

Due to the complexity and volume of computation of these methods and other methods, computers use these methods to be more precise in addition to speeding up simulation time. In this regard, various software for modeling and simulation of different phenomena have been created and accordingly, various software applications have been developed in water resources for different systems that are widely used today. Below we introduce and simulate several software applications of water resources systems.

Dams are one of the most important water resource systems. PLAXIS software is one of the software used in modeling underground dams. PLAXIS software is one of the most powerful and widely used software in the field of geotechnical engineering. Various versions of PLAXIS software have been released, including two-dimensional and three-dimensional versions, as well as tunnel versions of the software, and have different applications. One of the areas that use the two-dimensional version of PLAXIS software for analysis and analysis is the axial and symmetric strain analysis. Two-dimensional PLAXIS software is widely used in the fields of calculating the coefficient of reliability and analysis of stability states and using the software in simulation branches of the consolidation process, loading under load control modes and variable location control, analyzing and studying conditions Boundary water flow, pore water pressure analysis and analysis of boundary conditions of geometry in a particular problem have increased dramatically. The 3D version of PLAXIS software, known as PLAXIS-3D, is used to analyze issues in 3D. In the introduction of PLAXIS 3D software, it should be noted that the software has some limitations in terms of the features that it provides to the two-dimensional version of the software and its strengths are the three-dimensional problem analysis, Although PLAXIS-3D is capable of analyzing in three dimensions, loading analysis in this version of PLAXIS software can only be performed under load control conditions. The boundary conditions in the 3D PLAXIS software are defined as standard and the user is not able to change the boundary conditions while performing the PLAXIS project. It is not possible to check the pore pressure in this version of the software unlike its two-dimensional version. In PLAXIS-3D, the depth visibility is not defined, and the mesh defined in the PLAXIS 3D plan is the same at all depths. Simulation in the geogrid, tunnel and geotextile domains is not possible in the 3D version of PLAXIS software, but it is possible to analyze and model the plate items in which such items can be piles and Page pointed out. It should be noted that in the three-dimensional version of PLAXIS software, the c-phi reduction method cannot calculate the confidence factor.

The latest version of PLAXIS software to explain, is the 3D version of the tunnel, which is introduced as PLAXIS-3D TUNNEL and the software is capable of analyzing problems in two and a half dimensions. In explaining the concept of analysis in two and a half dimensions it should be noted that in the analysis with PLAXIS-3D TUNNEL, the software will draw one section of the tunnel and repeat the other section. The PLAXIS software makers have identified and reviewed these vulnerabilities, and the software panel has made significant improvements in all its versions compared to the past. The possibility of 3D analysis in many areas of science has been provided in the 3D version of PLAXIS software, and in parallel with the aforementioned possibility, the processing speed in this software has also increased significantly, which has led to the 3D version of the software being analyzed. And to study many scientific areas of soil and subsurface applications in civil engineering (Sharif Consultants 2016).

Another software used to simulate the failure of dams due to floods is the Mike11 software. This software was developed by the Danish Hydraulic Institute (DHI) and is capable of simulating one-dimensional flow, sediment transport and water quality in unstable rivers, estuaries and irrigation networks. The program uses the finite difference method to solve one-dimensional governing equations of flow, sediment transport, and water quality. The hydrodynamic model is actually the underlying element of all the systems mentioned (Komasi et al. 2015).

In water distribution and distribution systems, WaterGEMS software is one of the most widely used and simplified software for modeling and simulation of these systems and has the ability to run in Arc GIS, AutoCAD, microwave or separate environments. This program has many capabilities that can be mentioned: calculation of speed, pressure and other hydraulic parameters, simulation of fire state, simulation of water quality (pollution modeling in distribution networks [WaterGEMS], concentration calculation Pollutants after entering the grid and at specific times), energy cost calculations and more advanced topics such as designing and optimizing the water distribution network using genetic algorithm, finding the location of water leakage in urban water distribution networks and so on. WaterGEMS software is a full-fledged version of WaterCAD software and has the added features of WaterCAD software. Features of WaterGEMS more than WaterCAD include the Skelebrator module, Darwin tools module and SCADA Connect module. WaterGEMS software also has the ability to integrate and sync with AutoCAD and ArcGIS software, which WaterCAD software is unable to do. It should be noted that all files created by this two software are easily executable in one another, without any interference. Just have two versions of one software (Water GEMS Iran).

Also, EPANET is one of the most powerful water distribution network analysis software developed by the US Environmental Protection Agency (EPA) for free. EPANET is a computer program that simulates the hydraulic and qualitative behavior of water inside a pressure pipe network. A network consists of pipes, nodes, pumps, valves, and storage tanks or tanks. EPANET simulates the water flow in each pipe, the pressure in each node, the height of the water in each tank, and the concentration of one type of chemical throughout the network over a period. Typically, this software cannot design (determine pipe diameters), only with engineering knowledge and trial and error can the diameters of the distribution network be determined to estimate pressure and speed constraints. In branch networks this is possible, but in networks where the number of loops is high, it will not be possible to determine the diameter of the pipes by trial and error. One of the popular and widely used versions of this program (and of course unfamiliar in Iran) is the version of WaterNetGen which is one of the important features added by specifying the network constraints (speed and pressure) and specifying the diameter The available pipes and the Heizen-Williams coefficient of each design the grid program to satisfy the constraints (Parsian Modern Training Center).

Nowadays there are several software for simulating the model of groundwater, the most important of which is GMS and MODFLOW. GMS supports a variety of models and provides a great deal of information sharing between different models and data types. This software is a comprehensive and graphical environment for groundwater modeling. The GMS contains an interface, cartographic and several codes used in modeling such as UTCHEM, FEMWATER, SEEP2D, MODPATH, SEAM3D, RT3D, ART3D, MODEM, MT3DMS, MODFLOW, PEST, and UCODE.

The GMS software was developed by the Environmental Modeling Research Laboratory of Brigham Young University. MODFLOW is a three-dimensional model of saturation, finite difference, and block axis developed by the US Geological Survey and used in steady-state and unsteady-state analyzes. GMS is regarded as a very powerful pre-processor and post-processor for the MODFLOW 2 code. Input data for MODFLOW are provided by GMS and stored in files that are called by MODFLOW when GMS is launched. MODFLOW can be networked in both software and cellular center (One Search).

MODFLOW software was first introduced in 1984 as a three-dimensional finite-difference model. The MODFLOW code provided to simulate three-dimensional groundwater flow includes the main program and several sub-programs that are subdivided into several stand-alone software. Each software package is used to simulate one of the hydrological systems such as river feeding, drainage, water abstraction by wells, or to solve linear flow equations by a specific method. Splitting the code into several sub-programs makes it easy for the user to simulate hydrological aspects. On the other hand, it is possible to add new features and parts without having to correct the existing ones. The code is in FORTRAN 77 language and applies to many computers with FORTRAN 77 compilers. The benefits of this model are:

- Solves the equation using a finite difference method that is easy to understand.
- Works on many different computers.
- Used in one-dimensional, two-dimensional, half-dimensional, and three-dimensional modes.
- Its simulation aspects have been thoroughly tested.
- There is a lot of material and publications about it.
- Can simulate various effects of an aquifer, which includes: pressure and free aquifer, reservoir changes, bedrock and areas that are outside the aquifer but affect water flow, rivers that Aquifers are in exchange for water, drainage and springs that discharge water from the aquifer, seasonal springs, reservoirs that exchange water with the aquifer, rainfall and irrigation, evaporation and perspiration, and feed or drain wells.

The model inputs must include the aquifer properties for each cell. Also, if we have other information about other tolls, including wells, rivers, drainage, flow barriers, etc., we must include them. At the model outputs, after solving the equations by the model, parameters such as groundwater head at different time steps, groundwater level alignment curves, water balance and flow rate for each cell are extracted (concepts and models). Groundwater).

The SWAT model is currently widely used in Europe and the US to estimate and assess the impacts of global climate change on water resources and their quality. In the late 1980s, the American Agricultural Research Institute recognized the need for a model to simulate river flow larger than 1000 km^2. The SWRRB model was only responsive to basins up to 100 km^2. This model was only able to calculate the sub-basin parameters with 10 sub-basins, thus requiring the ROTO model.

The model captures and connects multiple SWRRB simulation outputs. Due to a large amount of input and output data, the two SWRRB and ROTO models were combined and replaced with a single SWAT model. Various versions of this model including SWAT 94/2, SWAT 96/2, SWAT 98/1, SWAT99/2 and SWAT2000 have been developed over time. SWAT 94/2 was developed based on several hydrological response units (HRUs). In SWAT model 2.96, agricultural irrigation and fertilizer parameters were added to the model as management components. This was the first edition in which the CO2 increase parameter was added to the model to model plant growth due to climate change. In this edition, the evapotranspiration equation was added to the model using the Penman-Montez method, lateral flow calculations, nitrogen content equations and pesticide estimation. In the SWAT version 98/1 the model was modified for use in the Southern Hemisphere. Other refinements of this edition include the refinement of the snow melting equations and the refinement of the nitrogen cycle calculations. SWAT 99/2 modified the nitrogen cycle process, modified the wetland calculation process, added nutrient drainage parameters to the wetland, reservoir, and lake. Also corrective and adaptive formulas with urban areas were added to the model. In SWAT 2000 editing, adding bacterial transfer formulas, adding Green and Ampt equations to the model to calculate infiltration, modifying production data and reconstructing climatic data, the possibility to enter radiation parameters, relative humidity, wind speed, evaporation, and transpiration was done by the user or simulated by the model. In addition to all the changes made to this model editing, in order to make it easier for users to interact with the model, an interface with Windows was developed through ArcView software. This model is able to simulate various parameters in great detail for large scale watersheds with low cost and short time. SWAT can simulate the long-term effects of the parameters in the basin and under different scenarios. This model is time-dependent and long-term modeling and is not designed to simulate single flood events. The SWAT model has a physical basis and can be used in watersheds that do not have regular inventory. This model uses easily accessible input data. The SWAT model is an efficient computation that performs simulations of very large basins with different management solutions with very low investment in the shortest time and the user will be able to study the long-term effects. In the tenth (2000) edition of AVSWAT, using ArcView software is a graphical environment for the SWAT model. SWAT is a model for simulating river basin parameters and predicting management plans, sedimentation, large-scale agricultural chemical parameters, and basins with different diversity in soil type, vegetation type and different land use as well as for different management conditions in the length of the courses are long. This model is a physical model that enables the user to study and compare the desired effects over a long period of time with different inputs. The model can also be studied in different contexts and in different basins for modeling water quality parameters. In the SWAT 2009 edition, bacterial transfer formulas have been further developed and various weather forecasting scenarios have been added. A generator has also been added to produce rain data in less than a daily time. Also the protection parameters used in daily CN calculations depend on the soil